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INSULATION, COMPRESSIBILITY AND ABSORBENCY OF DRY SUIT UNDERGARMENTS

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Selection of new undergarments (U/G) for cold water diving, which is by diver preference in the U.S. Navy, has recently been based on anecdotal reports rather than scientific evidence. Previous studies in 1982 revealed hydrophobic microfibrous material (Thinsulate) to be superior in both insulation when wet and compressibility compared to open-cell foam. The objectives of this study included comparing Thinsulate against the new U/G materials in a controlled, unmanned study. Following a market survey and preliminary testing of 39 U/G composites, nine U/G were chosen: four using arctic fleece, radiant barrier and both Thinsulate and polyester battings from Defense Marketing Consultants (DMC), four using Thinsulate M-400 and M-600 from Diving Unlimited International (DUI) and the Flectalon U/G composite from Arktis Outdoor Products. All U/G samples were 12 inches by

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12 inches (30.5 cm by 30.5 cm). Thermal conductivity was measured in a calibrated, Rapid-k instrument (Holometrics, Cambridge, MA). Multiple trials verified accuracy and reproducibility for all U/G tested. Significant difference between U/G samples was achieved by ANOVA and Tukey HSD tests with $p < 0.05$ accepted as significant. Compressibility data at 1.1 psi (2.5 FSW equivalent suit squeeze) demonstrated Flectalon most compressible (-60.7%), DMC moderately compressible (-48.6%) and DUI least compressible (-34.5%). Further compression to 2.2 psi (5.0 FSW) was minimal. Absorbency testing was analyzed for the water weight gain for the U/G, per se, and U/G per unit thickness. Overall, DMC U/G were very absorbent compared to DUI and Flectalon U/G. Insulation values were analyzed dry and wet (saturated), at 1.1 psi for both the U/G, per se, and U/G per unit thickness. In summary, dry U/G per unit thickness showed few differences, range 1.55 ± 0.02 to 1.78 ± 0.11 Clo/cm (mean ± SD, N=5). Saturated with water, the superior U/G, per se, were Flectalon, DUI M-600 and one DMC U/G using Dupont Dacron-II™ batting. The range was 0.14 ± 0.01 to 0.19 ± 0.07 Clo. The superior wet U/G, per unit thickness, included the above and M-400 DUI U/G, the range being 0.21 ± 0.03 to 0.32 ± 0.08 Clo/cm. In conclusion, rating compressibility, absorbency and insulation (wet), the superior U/G included Flectalon and DUI U/G, M-400 and M-600 weights. DMC U/G were ranked next, primarily due to high absorbency. The DMC radiant barrier did not significantly affect insulation by contributing any reflected radiant energy based upon the small temperature gradient between skin and water according to work done by Stefan and Boltzmann.

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I. INTRODUCTION

Selection of dry suit undergarment material has recently been based on personal preference and anecdotal evidence of undergarment thermal performance without any measurement of heat flux or heat loss by calorimetry in divers. In 1982, a well-controlled, unmanned study determined that a hydrophobic, microfibrous material (Thinsulate, 3-M Corporation, St. Paul, MN) was superior in both insulation and compressibility compared to the commonly used open-cell foam undergarment material (1).

Presently, an international market survey conducted at the Navy Experimental Diving Unit (NEDU) has obtained 39 different undergarment combinations that are being considered for use in extreme cold water diving (28.4° to 35 °F, -2.0° to 1.7 °C). Many are using new materials never evaluated for thermal protection. From these 39 undergarment samples, a preliminary evaluation at NEDU has determined that nine undergarments were the most promising for superior insulation, both dry and wet. Included in this evaluation were the most commonly used undergarments by cold water diving units in the U.S. and Royal Navies, as determined by an informal survey. With undergarment selection, like dry suit selection, being by diver preference in the U.S. Navy (2), NEDU then conducted a controlled, unmanned study of these nine dry suit undergarments. This study was part of a larger task to man test and evaluate diver Passive Thermal Systems (PTS), such as dry suits and undergarments.

The thermal performance of these undergarment materials was determined by measuring thermal conductivity which allowed a calculation of insulation, both dry and wet. Dry suit squeeze also limits thermal insulation by compressing the layer of trapped dead air space. Therefore, the degree of undergarment compressibility was measured at typical dry suit squeeze levels. Since all dry suits eventually develop leaks due to improper use, defects in material or lack of attention to routine dry suit maintenance, the degree of undergarment water absorbency was also measured. A flooded dry suit not only decreases insulation, trapped water may also create a dangerous negative buoyancy problem underwater. In addition, the weight of the absorbed water within the undergarment may make it impossible for the diver to exit the water without topside assistance. In certain combat or rescue swimming situations, topside assistance may not be available.

Beyond insulation, compressibility and absorbency, manned evaluation of undergarments should also evaluate the human factors of dexterity, flexibility and overall ability to swim as well as the actual measurement of heat loss using these various undergarments. In our research on Passive Thermal Systems (PTS), we could only devote time to selecting one optimal undergarment for both human factors and thermal physiological evaluation of diver performance during extreme cold water, long duration dives in the cold water swimming flume at NEDU. In an effort to assist U.S. Navy cold water divers in Special Warfare (SPECWAR), Explosive Ordnance Disposal (EOD), the Underwater Construction Teams (UCT), and Mobile Diving and Salvage Units (MDSU) the results of this study allowed us to rank the performance of these nine undergarment materials to better help divers select optimal undergarments.

II. METHODS

A. UNDERGARMENTS

Using the manufacturing and undergarment composition key below, the nine undergarments tested are found in Table #1. All undergarment samples were new, 12 in. by 12 in. (30.5 cm by 30.5 cm) swatches received directly from the manufacturers. From Defense Marketing Consultants (DMC), there were four undergarments using Arctic Fleece, a thick flannel-like material. These undergarments also had a mylar, radiant film which the DMC company claimed to reflect body heat back to the diver. The insulative batting layers in the DMC undergarments included both polyester and Thinsulate material. The DMC, B sample is known commercially as DMC 27^{o}, formerly called Underwave. DMC, B uses a batting made of Dacron-II™ polyester, not Thinsulate. It is the preferred undergarment by SPECWAR Swimmer Delivery Vehicle (SDV) Team One. Flectalon is a production composite undergarment preferred by the Special Boat Squadron (SBS) of the United Kingdom (U.K.) Special Forces, Royal Navy. The M-400 weight of Thinsulate is currently issued to the EOD U.S. Navy Divers using a crushed neoprene dry suit. The M-600 Thinsulate is made of two layers of M-400 and M-200 weight Thinsulate, also used by various cold water diving units in the U.S. Navy. The Thinsulate tested had either a flannel or vapor impermeable nylon covering on one side with vapor permeable nylon on the other side.

B. COMPRESSIBILITY TESTING

The thickness of each sample, in inches and cm, was repeatedly measured in the uncompressed and compressed state using a caliper. The degree of dry suit squeeze for an equivalent depth of 2.5 feet of sea water (FSW) is 1.1 pounds per square inch (PSI). This would approximate the depth of the feet in a diver, free-swimming. Likewise, in the erect position underwater, 5.0 FSW would be 2.2 PSI of suit squeeze. Using lead weights equally distributing weight over a known surface area of the undergarment material, caliper measurement were repeated three times and averaged to determine the degree of dry suit squeeze.

C. ABSORBENCY TESTING

In order to simulate a dry suit leak, there are two ways to determine the degree of absorbency. Completely saturating the undergarment would determine the maximum amount of water retained. This, however, was very difficult to control with much of the water coming out of the undergarment when it was removed from the water. Being that leaks mostly develop in the upper extremities, neck seal and upper torso zipper in dry suits, most water usually migrates through the material down to collect in the feet. Therefore, we completely saturated the undergarments overnight in a bath and after removing them from the water, they were allowed to drain until the dripping stopped.

The wet undergarments were then weighed, in a plastic bag, on an electronic scale, tared for the weight of the bag. This was the most reproducible way for us to simulate dry suit leaks. The mean weight of wet samples over five different soakings is reported in grams, as well as percent increase over the dry weight. The absolute weight of water weight gain is also reported which may be useful to predict loss of buoyancy from a flooded dry suit.

Multiple measurements were made of the dry weight, wet weight, water weight gain for the undergarment and the undergarment per unit thickness allowing comparison between undergarment materials. These multiple trials allowed statistical tests, Analysis of Variance (ANOVA) followed by the Tukey Highly Significant Difference (HSD) test, to determine significant differences, accepted at the $P < 0.05$ level.

D. THERMAL CONDUCTIVITY TESTING

The effectiveness of these undergarments to act as insulation was first determined by measuring their ability to conduct heat, i.e., thermal conductivity, which allowed a calculation of the degree of insulation. This was repeatedly measured in all undergarments using a calibrated thermal conductivity instrument (Rapid-k, Holometriccs, Inc., Cambridge, MA). The unit of thermal insulation, the Clo, was then calculated from the thermal conductivity measurements. Results of compressibility testing confirmed that further compression from 2.5 FSW to 5.0 FSW did not compress the undergarment more than 3.2 to 13.1%. Therefore, all thermal conductivity measurements were made with a simulated suit squeeze of 2.5 FSW by compressing the undergarment sample in the Rapid-k instrument. By using a plastic bag, which was determined not to influence the measurement of thermal conductivity, no water was lost when the sample was compressed in the Rapid-k instrument. Calculations of thermal insulation for both the undergarment, per se, and per unit thickness were made for each undergarment, dry and wet. This permitted a comparison of insulation between undergarments, as well as the material, per unit thickness.

The owner's manual of the Rapid-k instrument emphasized that for accurate conductivity measurements, the ratio of the thermal conductivity coefficient, k to the thickness of the material being tested should not exceed 2 $BTU/hr{*}ft^2{*}{}^\circ F$ which is also 12 $W/m^2{*}{}^\circ F$ (page 13, reference 3). In order to satisfy this requirement, all wet samples were tested in series with one sheet of Thinsulate M-400 batting on top of the cold plate. The reported data excludes this layer of Thinsulate.

The actual measurement of thermal conductivity in the Rapid-k instrument was made by measuring the heat flux between a temperature controlled cold plate and warm plate. Temperatures chosen for the cold and warm plates simulated the water temperature and skin temperature during a typical long duration dive in 32°F (0°C) water. The five equations below simply explain how the calculation of insulation in units of Clo were made in this study. A more detailed review of measuring the thermal characteristics of damp hydrophobic, microfibrous batt was reported by Steele in 1987 (4).

1. Heat Flux.

$Q = q * y$ Equation (1)

where:	S.I units	English units
Q = heat flux engineering units	W/m^2	$BTU/hr*ft^2$

with: W=watts, m=meters, BTU=British Thermal Units, hr=hour and ft=foot.

q = Rapid-k heat flux in units of mV, millivolts

y = calibration constant

2. Temperature, using "T"-type thermocouples in the Rapid-k instrument.

$T = A + B*e + C*E^2$ Equation (2)

where:	Celcius	Fahrenheit
T = temperature		
E = temperature measurement in mV for hot and cold plates.		
A =	0.0 °C	32.2 °F
B =	25.8 °C	78.4 °F
C =	-1.10	-0.611

3. Conductive Heat Transfer Coefficient, k

k = q * (delta x/delta T) Equation (3)

where:	S.I. units	English units
k = Conductivity heat transfer coefficient	$W*cm/m^2*°C$	$BTU*in/hr*ft^2*°F$
delta x = distance between plates	cm	in
delta T = temperature difference between hot and cold	°C	°F

4. Insulation value, Clo

Clo = delta x / k * z Equation (4)

where:
z = conversion factor 0.155 $°C*m^2/W*Clo$ in S.I. units
0.88 $°F*ft^2*hr/BTU*Clo$ in English units

5. Insulation value per unit thickness

Clo / thickness in cm Equation (5)

TABLE #1A

MANUFACTURER KEY

AOP = Arktis Outdoor Products (Exeter, England)

DMC - Defense Marketing Consultants (Seattle, Washington)

DUI = Diving Unlimited International (San Diego, California)

COMPOSITION KEY

A = Nylon (Taslin), one layer

B = Nylon (Taffeta), one layer

C = Nylon (Taffeta), coated with neoprene (vapor barrier)

D = Mylar radiant film, two layers, with three alternating layers of fine nylon netting

E = Arctic fleece, 16 oz polyester

F = Dacron II (DuPont), 4 oz batting covered on both sides with one layer each of mylar and fine nylon netting.

G = Thinsulate (3-M), M-400 batting

H = Thinsulate (3-M), M-200 batting

I - Thermolite (DuPont), 8 oz batting

J = Pertex, lightweight nylon, one layer (4 oz)

K = Flectalon filaments, polymer or PVC small filaments, coated with aluminum (150 gm) covered by a scrim.

L = Slimtex polyester batting (3.3 to 18.0 d'tex fiber size) covered on both sides by a thin bonded layer and on one side by 2 oz nylon.

M = Bodypelt, 100% nylon pile, 3 mm.

N = Flannel, thin, bonded layer.

TABLE #1B: UNDERGARMENT SAMPLES

SAMPLE #	SAMPLE NAME	MANUFACTURER	COMPOSITION (OUTSIDE TO SKIN SIDE)
1	Arctic Fleece	DMC	E, E*
2	DMC, B	DMC	A, D, F, D, E
3	DMC, C	DMC	A, D, D, I, D, E
4	DMC, W	DMC	E, D, H, D, E
5	Flectalon	AOP	J, K, L, M**
6	M-400 Flannel Backing	DUI	B, G, N
7	M-400 with Neoprene Vapor Backing	DUI	B, G, C
8	M-600 Flannel Backing	DUI	B, G, H, N
9	M-600 with Neoprene Vapor Backing	DUI	B, H, G, C

* Sample #1 is two sheets of Artic Fleece.

** Sample #5 is a production composite.

III. RESULTS

A. COMPRESSIBILITY TESTING

The results of the compressibilty testing are found in Table #2. In summary, compressibility data at 2.5 FSW (1.1 PSI) of simulated suit squeeze ranged in percent change from -30.4% for M-400, flannel Thinsulate to as high as -62.5% for the DMC, C sample. Figure #1 illustrates the changes in compressibility for all the undergarment samples.

B. ABSORBENCY TESTING

Table #3 lists the results of absorbency testing for both the undergarment, per se, and per unit thickness. The results are best illustrated in Figure #2. For such a great number of comparisons, Tables #4 and #5 list the statistically significant differences for the water weight increase for the garment and garment per unit thickness, respectively. Also noted in Tables #4 and #5 are Group numbers 1 - 3, arbitrarily selected to rank the undergarments. In summary, DMC and especially Artic Fleece undergarments were significantly shown to be much more absorbent over the four Thinsulate undergarments and the Flectalon undergarment. This held true for the undergarment, per se, and per unit thickness.

C. THERMAL CONDUCTIVITY TESTING

In Table #6, the results of dry and wet insulation for the undergarments, per se, and per unit thickness are listed. Figures #3 and #4 show these comparisons for wet vs. dry undergarments. Supporting Figures #3, are Tables #7 and #8 which demonstrate statistically significant differences between dry and wet undergarment samples. Likewise, the statistical comparison between dry and wet undergarment samples per unit thickness are found in Tables #9 and #10. In summary, the degree of insulation of dry undergarments was, of course, related to their thicknesses and ranged from 0.67 to 1.07 Clo. As expected, the differences between dry undergarments per unit thickness was very small ranging from 1.56 to 1.78 Clo/cm.

The important comparisons were between wet undergarment samples. Both of the M-600 Thinsulate undergarments were not significantly different in insulation from Flectalon. Although there was no significant difference between Thinsulate and DMC, B, Flectalon was found to be significantly better in insulation than DMC, B. When comparing the insulation per unit thickness between wet undergarments, there were no significant differences between Thinsulate, Flectalon and DMC, B.

Overall ranking of the nine undergarments for absorbency by water weight gain and insulation both dry and wet, is best shown in Table #11, using a 1 to 3 scale.

TABLE #2 - COMPRESSIBILITY

SAMPLE # AND NAME	UNCOMPRESSED* (CM)	1.1 PSI** (CM)	2.2 PSI* (CM)	A. UNCOMPRESSED TO 1.1 PSI (% CHANGE)	B. UNCOMPRESSED TO 2.2 PSI (% CHANGE)	A-B (%)
1 Artic Fleece	.813	.483	.432	-40.6	-46.9	-6.3
2 DMC, B	.787	.432	.406	-45.2	-48.4	-3.2
3 DMC, C	1.626	.610	.599	-62.5	-65.6	-3.1
4 DMC, W	1.245	.660	.610	-46.9	-51.0	-4.1
5 Flectalon	1.422	.559	.457	-60.7	-67.9	-7.2
6 M-400 Flannel	.584	.406	.330	-30.4	-43.5	-13.1
7 M-400 Vapor Barrier	.597	.406	.368	-31.9	-38.3	-6.4
8 M-600 Flannel	1.080	.622	.533	-42.4	-50.6	-8.2
9 M-600 Vapor Barrier	.914	.610	.533	-33.3	-41.7	-8.4

* Average of three tests.
** Average of six tests.

FIGURE # 1 COMPRESSIBILITY

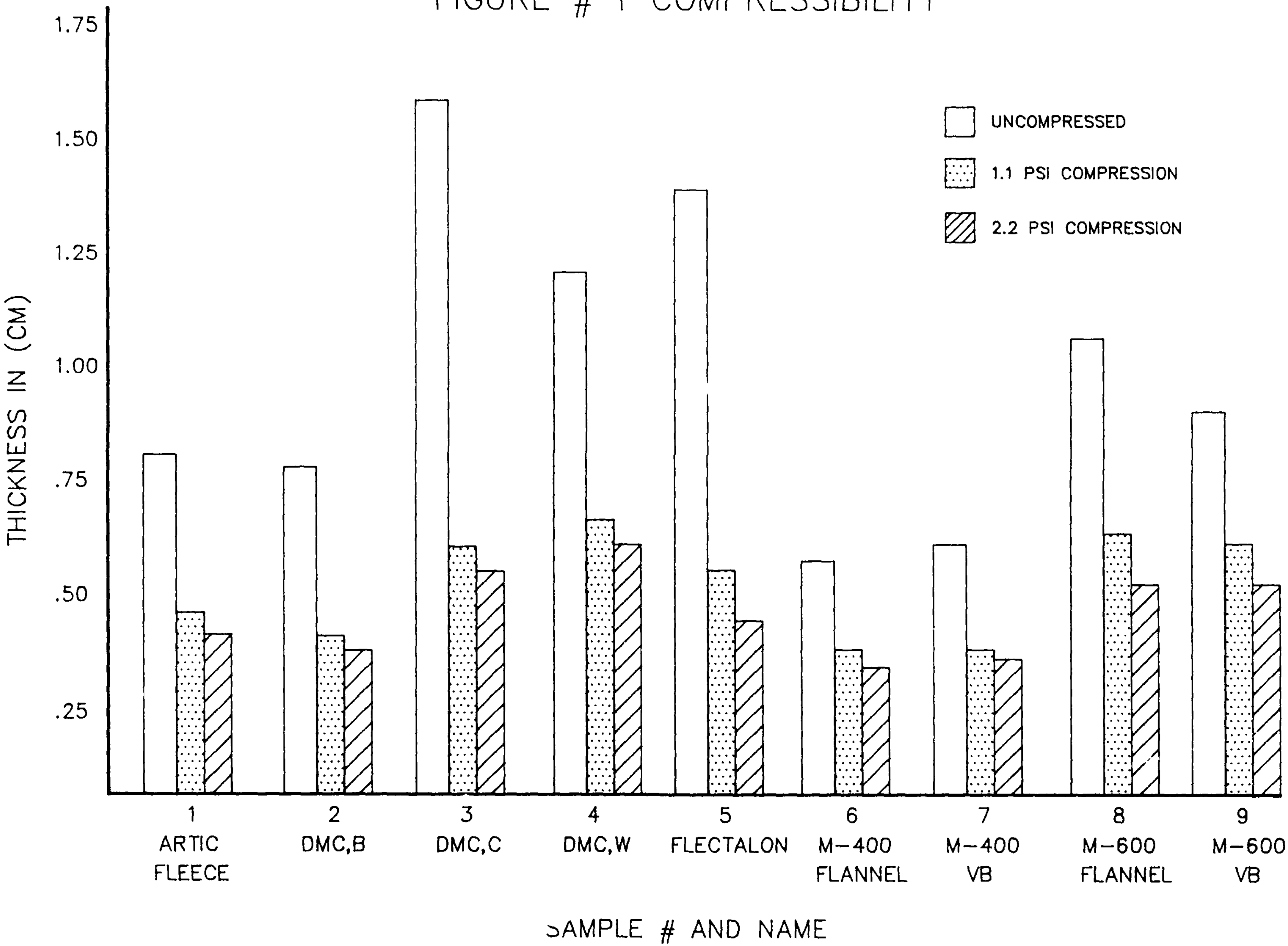

TABLE #3 - DEGREE OF ABSORBENCY: GARMENT AND GARMENT/CM

SAMPLE # AND NAME	DRY WEIGHT* (G)	WET WEIGHT** (G) ± SD	WEIGHT INCREASE (G) ± SD	DRY TO WET WEIGHT (% CHANGE)	WEIGHT INCREASE PER CM (G/CM) ± SD
1 Artic Fleece	54.4	363.4 ± 53.4	309.0 ± 53.4	568	639.8 ± 110.6
2 DMC, B	65.1	346.7 ± 14.9	281.6 ± 14.9	433	651.9 ± 34.5
3 DMC, C	71.9	489.0 ± 52.3	417.1 ± 52.3	580	683.8 ± 85.7
4 DMC, W	90.8	493.0 ± 25.7	402.2 ± 25.7	443	609.4 ± 38.9
5 Flectalon	79.7	251.3 ± 20.9	171.6 ± 20.9	215	307.0 ± 37.4
6 M-400 Flannel	68.1	181.9 ± 14.5	113.8 ± 14.5	167	280.3 ± 35.7
7 M-400 VB	74.4	188.6 ± 10.3	114.2 ± 10.3	153	281.3 ± 25.4
8 M-600 Flannel	94.9	275.9 ± 34.3	181.0 ± 34.3	191	291.0 ± 55.1
9 M-600 VB	89.6	258.3 ± 31.7	168.7 ± 31.7	188	276.6 ± 52.0

* Mean of three tests.
** Mean and standard deviation of five tests.

FIGURE # 2 DEGREE OF ABSORBENCY:
GARMENT AND GARMENT PER UNIT THICKNESS

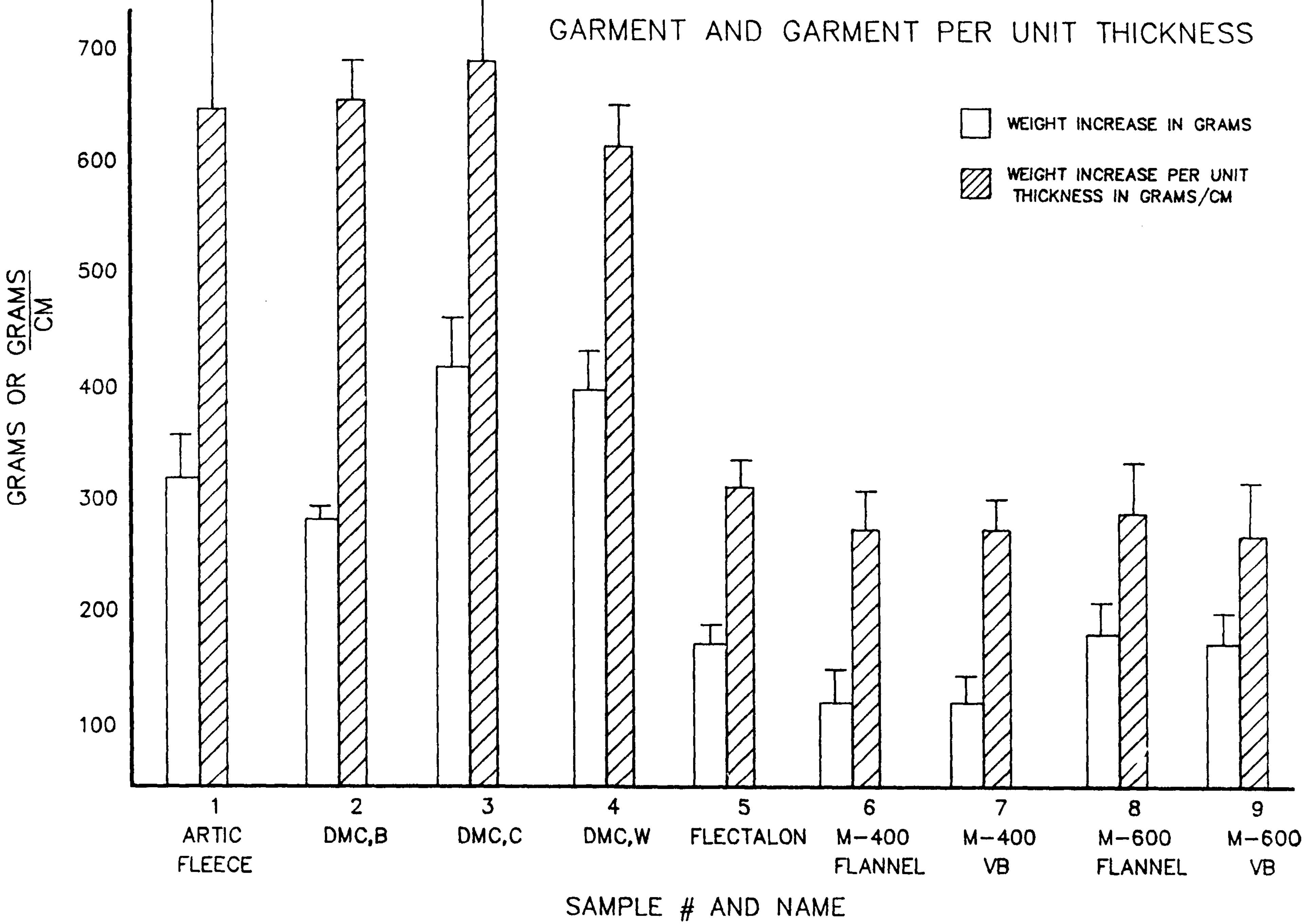

TABLE #4: MULTIPLE COMPARISON TEST (TUKEY - HONESTLY SIGNIFICANT DIFFERENCE) RESULTS FOR GARMENT WATER WEIGHT INCREASE

	SAMPLE #									GROUP
	6	7	9	5	8	2	1	4	3	
6 M-400 Flannel						*	*	*	*	
7 M-400 VB						*	*	*	*	
9 M-600 VB						*	*	*	*	1
5 Flectalon						*	*	*	*	
8 M-600 Flannel						*	*	*	*	
2 DMC, B	*	*	*	*	*			*	*	
1 Artic Fleece	*	*	*	*	*			*	*	2
4 DMC, W	*	*	*	*	*	*	*			
3 DMC, C	*	*	*	*	*	*	*			3

* Denotes pairs or groups significantly different at P < .05

TABLE #5: UNDERGARMENT (PER UNIT THICKNESS) COMPARISON, ABSORBENCY

	SAMPLE #									GROUP
	9	6	7	8	5	4	1	2	3	
9 M-600 VB						*	*	*	*	
6 M-400 Flannel						*	*	*	*	
7 M-400 VB						*	*	*	*	1
8 M-600 Flannel						*	*	*	*	
5 Flectalon						*	*	*	*	
4 DMC, W	*	*	*	*	*					
1 Artic Fleece	*	*	*	*	*					
2 DMC, B	*	*	*	*	*					
3 DMC, C	*	*	*	*	*					2

* Denotes pairs or groups significantly different at P < .05

TABLE #6 INSULATION: GARMENT AND GARMENT/CM

SAMPLE # AND NAME	CLO DRY* MEAN ± SD	CLO/CM DRY MEAN ± ISD	CLO WET* MEAN ± ISD	CLO/CM WET MEAN ± ISD
1 Artic Fleece	.749 ± .014	1.559 ± .029	.051 ± .024	.103 ± .044
2 DMC, B	.735 ± .007	1.657 ± .017	.119 ± .021	.276 ± .049
3 DMC, C	1.096 ± .070	1.780 ± .113	.094 ± .043	.155 ± .070
4 DMC, W	1.019 ± .011	1.550 ± .013	.071 ± .016	.109 ± .025
5 Flectalon	1.086 ± .101	1.765 ± .008	.192 ± .073	.315 ± .082
6 M-400 Flannel	.680 + .010	1.696 ± .031	.081 ± .011	.212 ± .029
7 M-400 VB	.668 ± .004	1.632 ± .011	.099 ± .010	.248 ± .024
8 M-600 Flannel	1.022 ± .005	1.657 ± .009	.140 ± .015	.231 ± .028
9 M-600 VB	1.065 ± .100	1.710 ± .031	.182 ± .017	.308 ± .030

* Mean and standard deviation of five tests.

FIGURE # 3 INSULATION
WET VS DRY

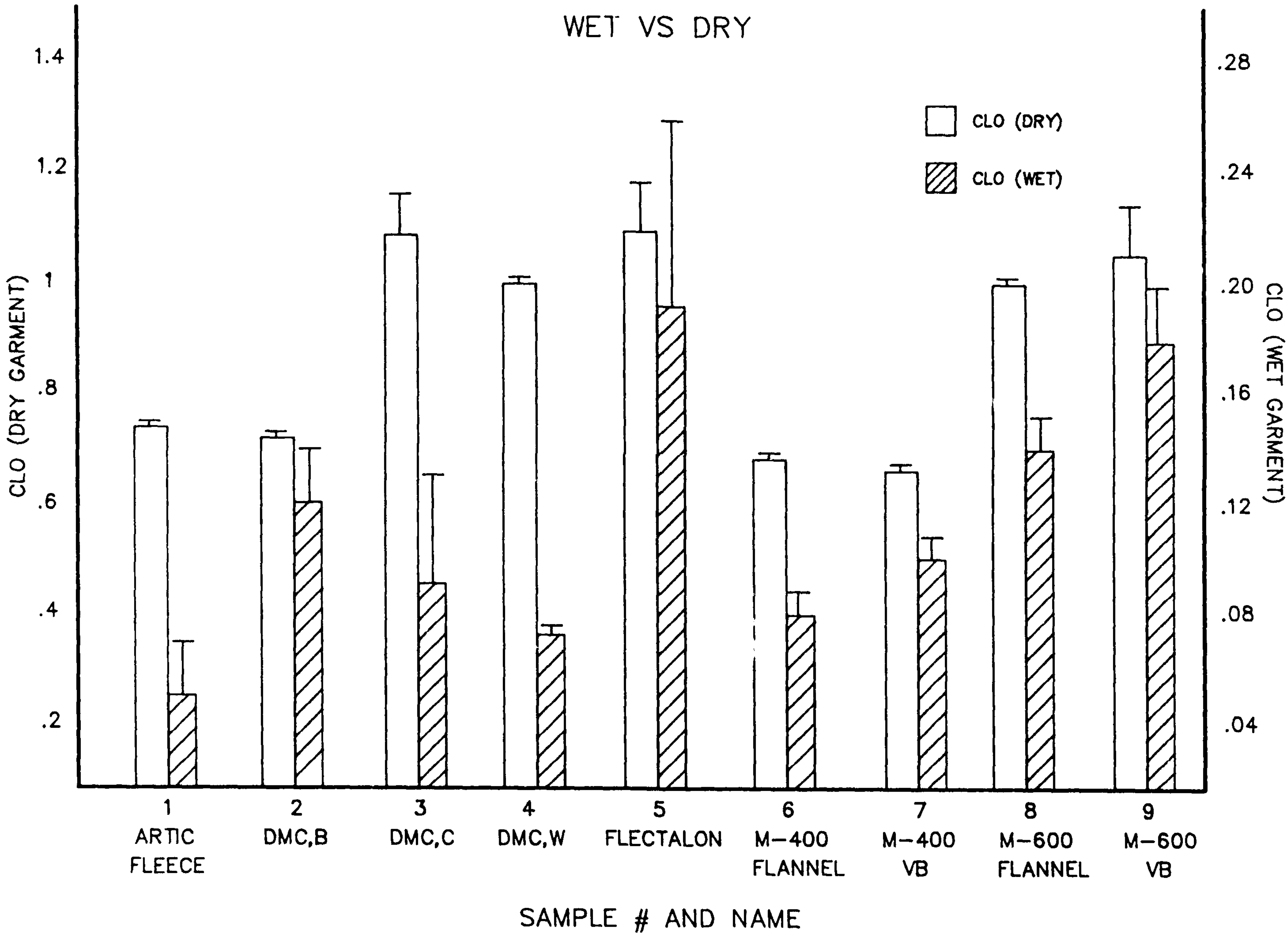

TABLE #7: UNDERGARMENT COMPARISON, DRY

		SAMPLE #									GROUP
		7	6	2	1	4	8	9	5	3	
7	M-400 UB						*	*	*	*	
6	M-400 Flannel						*	*	*	*	2
2	DMC, B						*	*	*	*	
1	Artic Fleece						*	*	*	*	
4	DMC, W	*	*	*	*						
8	M-600 Flannel	*	*	*	*						1
9	M-600 VB	*	*	*	*						
5	Flectalon	*	*	*	*						
3	DMC, C	*	*	*	*						

* Denotes pairs or groups significantly different at P < .05, Tukey - HSD statistical test.

TABLE #8: UNDERGARMENT COMPARISON, WET

		SAMPLE #								
		1	4	6	3	7	2	8	9	5
1	Arctic Fleece						*	*	*	*
4	DMC, W							*	*	*
6	M-400 Flannel								*	*
3	DMC, C								*	*
7	M-400 VB								*	*
2	DMC, B	*								*
8	M-600 Flannel	*	*							
9	M-600 VB	*	*	*	*	*				
5	Flectalon	*	*	*	*	*	*			

* Denotes pairs or groups significantly different at P < .05

FIGURE # 4 INSULATION PER UNIT THICKNESS

WET VS DRY

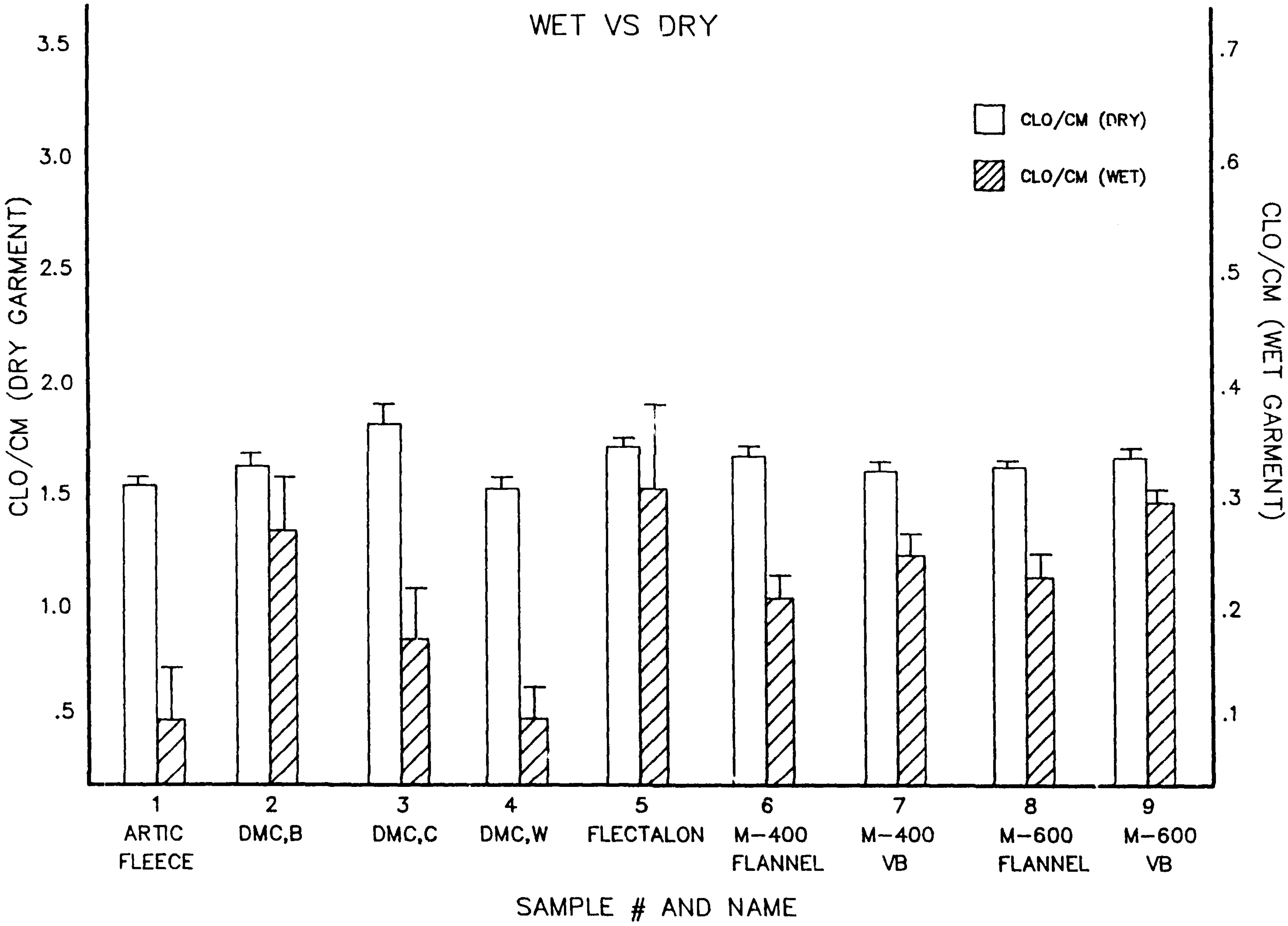

TABLE #9: UNDERGARMENT (PER UNIT THICKNESS) COMPARISON, DRY

	SAMPLE # 4	1	7	2	8	6	9	5	3	GROUP
4 DMC, W				*	*	*	*	*	*	2
1 Artic Fleece				*	*	*	*	*	*	
7 M-400 VB								*	*	
2 DMC, B								*	*	
8 M-600 Flannel	*	*								
6 M-400 Flannel	*	*								1
9 M-600 VB	*	*								
5 Flectalon	*	*	*	*	*					
3 DMC, C	*	*	*	*	*					

* Denotes pairs or groups significantly different at P < .05, Tukey - HSD statistical test.

TABLE #10: UNDERGARMENTS (PER UNIT THICKNESS) COMPARISON, WET

	SAMPLE # 1	4	3	6	8	7	2	9	5
1 Arctic Fleece				*	*	*	*	*	*
4 DMC, W				*	*	*	*	*	*
3 DMC, C							*	*	*
6 M-400 Flannel									*
8 M-600 Flannel	*	*							
7 M-400 VB	*	*							
2 DMC, B	*	*							
9 M-600 VB	*	*	*						
5 Flectalon	*	*	*	*					

* Denotes pairs of groups significantly different at P < .05.

TABLE #11: UNDERGARMENT RANKING

		WATER WEIGHT GAIN		CLO, DRY		CLO, WET	
		Sample	Per cm	Sample	Per cm	Sample	Per cm
1	Artic Fleece	2	2	2	2	3	3
2	DMC, B	2	2	2	1	2	1
3	DMC, C	3	2	1	1	2	2
4	DMC, W	3	2	1	2	2	3
5	Flectalon	1	1	1	1	1	1
6	M-400 Flannel	1	1	2	1	2	1
7	M-400 VB	1	1	2	1	2	1
8	M-600 Flannel	1	1	1	1	1	1
9	M-600 VB	1	1	1	1	1	1

IV. DISCUSSION

The best undergarments for insulation dry and, most importantly, wet were the M-600 Thinsulate undergarments and Flectalon. The M-400 weight Thinsulate undergarments are less thick but still have excellent insulating capacity when wet. There was no difference between flannel and vapor barrier Thinsulate samples. One negative feature of Flectalon is the high loft and compressibility, which may also explain why it is very difficult for operators using Flectalon to don their dry suits without great assistance. This high loft may also restrict mobility on-land during insertion exercises. In addition, Flectalon is an imported, composite undergarment relying on materials from outside the United Kingdom. Considering that Flectalon is equal in insulation to Thinsulate when wet, one can speculate that if Flectalon used the hydrophobic batting, Thinsulate, it would indeed become the most superior undergarment.

What detracts from the DMC, B undergarment is the very high water absorbency which could reduce insulation and buoyancy if there was a dry suit leak. The other DMC undergarments and Arctic Fleece were found to be very substandard for reasons of relatively high compressibility and absorbency giving overall poor insulation values when wet.

This method of measuring thermal conductivity cannot assess whether a vapor barrier could help to prevent heat loss from evaporation of water or perspiration from the skin. However, this study did demonstrate that the radiant barrier, Mylar, did not influence the value of thermal conductivity by relecting any energy. With the temperature difference between the diver's skin and the water being only 40°F, and much less within the insulation material, there would be no significant energy reflected back to the diver by any radiant barrier. Stefan's Law of reflected, radiant energy requires the temperature difference to be raised to the fourth power, thus requiring a very large temperature gradient for any appreciable radiant energy reflection. In the dry environment, especially at high altitudes or in space, radiant barriers do help to reflect away intense radiation from the sun.

V. CONCLUSION

Based upon undergarment ranking using water weight gain and insulation dry and wet, the most superior undergarments were M-600 weight Thinsulate and Flectalon. Thinsulate may be preferred over Flectalon due to being less compressible.

The next best undergarment is DMC, B. Although it is a good insulator if wet, it is very absorbent which may create a negative buoyancy problem with dry suit flooding. Being 50% less in insulating batting than M-600 weight Thinsulate, M-400 weight Thinsulate is also a good insulator, even wet, for shorter duration dives or dives in moderately cold water. The other DMC undergarments and Arctic Fleece were not acceptable due to high compressibility, absorbency and poor insulation if wet.

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REFERENCES

1. Nuckols, ML and MW Lippitt. Technical Note, NCSC TN 609-82. Engineering Development and Testing of the Passive Diver Thermal Protection System. March, 1982.

2. United States Navy Diving Manual, Volume One, Air Diving. NAVSEA 0994-LP-001-9010. Revision One, 1 June 1985, Navy Department, Washington, D.C., Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., Stock No. 008-046-00094-8.

3. User's Manual for the Rapid-k Heat Flow Meter Thermal Conductivity Instrument. Dynatech R/D Company, A Division of Dynatech Corporation, 99 Erie St., Cambridge, MA 03149.

4. Steele, K.A. Thermal Characteristics of Damp Hydrophobic, Microfibrous Batting. Journal of Energy Resources Technology, Vol. 110, No. 1, pp. 19-22, March 1988.